

Remarks

Overview

In the Office Action under reply, the first Action on the merits, claims 1-36 are pending. The claims have been rejected as follows:

(1) claims 1-36 are rejected under 35 U.S.C. §112, first paragraph, as failing to comply with the enablement requirement;

(2) claims 1-36 are rejected under 35 U.S.C. §112, first paragraph, as failing to comply with the written description requirement;

(3) claims 1, 4-6, 11, 13-18, 21-25, 27, 32, and 36 are rejected under 35 U.S.C. §103 as unpatentable over US 5,653,951 to Rodriguez ("Rodriguez") in view of Inagaki et al., (2001), *Determining Factors for the Intercalation into Carbon Materials from Organic Solutions*, 39 Carbon 1083 ("Inagaki");

(4) claim 26 is rejected under 35 U.S.C. §103 as unpatentable over Rodriguez in view of Inagaki, and further in view of Janot et al. (2001), *Ball Milling: A New Route for the Synthesis of Superdense Lithium GICs*, 39 Carbon 1931 ("Janot"); and

(5) claims 2-3, 8, 19-20, 29, and 34-35 are rejected under 35 U.S.C. §103 as unpatentable over Rodriguez in view of Inagaki and further in view of Chen et al., (1999), High H₂ Uptake by Alkali-Doped Carbon Nanotubes Under Ambient Pressure and Moderate temperatures, *Science*, 285, 91 ("Chen").

In addition, claims 7, 9-10, 12, 28, 30-31, and 33 are objected to for depending upon a rejected claim.

The rejections and objections are overcome in part by the amendments made herein, and are otherwise traversed for at least the reasons set forth below.

Claim construction

The Examiner has adopted the following construction for "pillared" in the claims: "a 'pillared' carbon material refers to the alteration of a carbon material in which parts of the carbon material are separated from each other by solvated alkali metal containing organic ligands" (Action at page 9). The Examiner's construction does not accurately capture applicants' express definition of the term "pillared," being both too broad and too narrow.

The Examiner's definition is too broad since intercalated carbon materials would be encompassed by "pillared carbon materials" according to the Examiner's construction. As defined in paragraph [00028] of the specification, however, a "pillared" carbon material differs from an intercalated carbon material. Intercalation is a step by which organic ligands and metal ions may be incorporated into the materials of the invention. However, as the specification states, "[t]he 'pillared' carbon material . . . differs from metal-doped or intercalated carbon materials in that the alteration (e.g. increased interlayer or intertube distance) is comparatively stable." This stability is part of the applicant's express definition of "pillared." To achieve this stability, the application proposes a *further chemical reaction* between the organic ligand and the carbon material (i.e., a reaction different from the intercalation reaction). This express definition is fully consistent with the specification and the claims. In particular, claim 17 would not make sense if intercalation produced pillared materials, since claim 17 recites an express further reaction, *in addition to intercalation*, to generate the pillared materials.

The Examiner's definition is also too narrow in that the separation is limited to being achieved by "solvated alkali metal containing organic ligands." The Examiner is taking a limitation which the applicants chose to place in one claim, claim 17, and saying that as a matter of claim construction the limitation is also found in claim 1, despite the fact that the applicants chose not to put it there. "There is presumed to be a difference in meaning and scope when different words or phrases are used in separate claims." *Tandon Corp. v. United States Int'l Trade Comm'n*, 831 F.2d 1017, 1023 (Fed. Cir. 1987). The Examiner's claim construction is not correct.

Rejection under 35 U.S.C. §112, first paragraph

Claims 1-36 stand rejected under 35 U.S.C. §112, first paragraph, as "failing to comply with the written description requirement" (Action at page 2). This rejection is traversed.

Claims 1-36 are as originally filed. It is most unusual to reject an originally filed claim for lack of written description. *See In re Koller*, 613 F.2d 819, 823-24 (CCPA 1980) ("[O]riginal claims constitute their own description. Later added claims of similar scope and wording are described thereby."); *see also* MPEP § 2163.

The Examiner states that "[a]pplicants have done little more than run a computer simulation... There is nothing in the Applicants' specification to suggest that Applicants have

made a composition described in [the] Claims...”

The Examiner’s rejection presupposes that a description of actual preparatory experiments is required for applicants to satisfy the written description requirement. This position is not supported by the relevant statute or case law. As stated in MPEP §2163.02:

...the fundamental factual inquiry is whether the specification conveys with reasonable clarity to those skilled in the art that, as of the filing date sought, applicant was in possession of the invention as now claimed. See, e.g., *Vas-Cath, Inc. v. Mahurkar*, 935 F.2d 1555, 1563-64, 19 USPQ2d 1111, 1117 (Fed. Cir. 1991)... Possession may be shown in a variety of ways including description of an actual reduction to practice, or by showing that the invention was "ready for patenting" such as by the disclosure of drawings or structural chemical formulas that show that the invention was complete, or by describing distinguishing identifying characteristics sufficient to show that the applicant was in possession of the claimed invention. (emphases added)

The presence of working examples or actual experimental details is clearly not a prerequisite to satisfy the written description requirement. The invention may be described *in any way* that demonstrates applicants’ possession of the invention as claimed. Describing actual preparations of the claimed composition is only one such way, but the specification describes the invention in sufficient detail to obviate the need for such experimental details.

The Examiner has not satisfied the requirements for presenting a rejection based on lack of written description. As described in MPEP §2163.04, it is the Examiner’s task to present a preponderance of evidence to challenge the adequacy of the written description

A description as filed is presumed to be adequate, unless or until sufficient evidence or reasoning to the contrary has been presented by the examiner to rebut the presumption. See, e.g., *In re Marzocchi*, 439 F.2d 220, 224, 169 USPQ 367, 370 (CCPA 1971). The examiner, therefore, must have a reasonable basis to challenge the adequacy of the written description. The examiner has the initial burden of presenting by a preponderance of evidence why a person skilled in the art would not recognize in an applicant's disclosure a description of the invention defined by the claims. *Wertheim*, 541 F.2d at 263, 191 USPQ at 97.

To support the rejection, the Examiner cites the lack of actual examples. As argued above, however, theoretical examples may be used to satisfy the written description requirement. The Examiner further cites applicants’ article in *Physical Review Letters* (2004), vol. 92, no. 16 (“the PRL article”). The PRL article, however, only states that the methods described in the current specification are theoretical. The PRL article therefore simply reaffirms the fact that the

examples in the current application describe simulations. The PRL article in no way states or suggests that such methods would not be successful.

The methods and compositions of the instant application rely on synthetic procedures that are well known in the art, but had not been used as described in the specification prior to the filing date of the application. The fact that “a number of techniques or steps may be utilized” does not diminish from the fact that such techniques or steps are: (a) known in the art; and/or (b) described in the specification. MPEP §2163.03: “there is a strong presumption that an adequate written description of the claimed invention is present in the specification as filed. In re Wertheim, 541 F.2d 257, 262, 191 USPQ 90, 96 (CCPA 1976).” In the present case, the extensive details provided, *inter alia*, in paragraphs [00037]-[00045] are sufficient for the skilled artisan to understand that applicants were in possession of the claimed compositions and methods at the time the application was made. Accordingly, applicants respectfully request withdrawal of the rejection.

Rejection under 35 U.S.C. §112, first paragraph

Claims 1-36 stand rejected under 35 U.S.C. §112, first paragraph, as “failing to comply with the enablement requirement” (Action at page 3).

The Examiner addresses eight factors as they relate to whether “undue experimentation” would be necessary to practice the invention (Action at pages 4-8). The pertinent factors are discussed below.

c. The state of the prior art

Many of the references cited in the specification were cited in an Information Disclosure Statement (IDS) submitted by applicants on 14 January 2005. Several others are cited in the Supplemental IDS submitted herewith. The Examiner acknowledges that the person of ordinary skill would be familiar with carbon nanostructures and their preparation, but asserts that a person of ordinary skill in the art would not be familiar with theoretical computer modeling. Even if the Examiner’s assertion were true, the pending claims are directed toward compositions and methods for their making; an understanding of theoretical computer modeling is not required in order for the skilled artisan to make the claimed compositions or to practice the claimed

methods. An understanding of synthetic chemistry is required, and the level of ordinary skill in the art of synthetic chemistry is high.

d. The level of predictability in the art.

The Examiner asserts that there is still some degree of unpredictability owing to the fact that the art deals with things on an atomic scale, citing a discussion of the Heisenberg Uncertainty Principle as evidence. Although one cannot debate the merits of the Heisenberg Uncertainty Principle, applicants point out that the claims are drawn to compositions and methods of making such compositions. The level of predictability in synthetic chemistry is relatively high. The reactions and methods required to make the claimed compositions are known, and are furthermore, known to be reproducible. Experimental results are not needed to verify applicants' calculations, because applicants are performing calculations on compositions that are prepared using known synthetic methodologies. Furthermore, the quantum chemical calculations which were employed to determine the properties of the claimed compositions take into account the Heisenberg Uncertainty Principle since they employ quantum mechanical models of matter (specifically Density Functional Theory). These models compute electron probability densities as opposed to exact electron positions; an electron probability density, unlike an exact electron position and momentum, is fully consistent with the Heisenberg Uncertainty Principle.

e. The amount of direction provided

The Examiner takes issue with the brevity of the description of the reactions that may be used to prepare pillared carbon materials. Citing paragraph [00045] of the specification, the Examiner states that "[t]he critical step in Applicants' process, namely adding the metal to the carbon nanostructures to produce a 'pillared carbon material' is described in one sentence." Applicants disagree with the Examiner's characterization of the process, and furthermore assert that the description in paragraph [00045] is sufficient for the skilled artisan to understand the intended method.

In particular, paragraph [00045] describes a three-step process. In the first step, "ternary compounds are first produced by the reaction between host carbons and solvated alkali cations, e.g. 2,5-dihydrofuran solvated Li cations, in low concentration such that the interlayer spaces of

graphite are expanded.” This step describes a simple intercalation reaction, such as the intercalation reaction described in Inagaki (i.e., the reference cited by the Examiner and described below). Experimental details for carrying out such a reaction are well known and widely available to the skilled artisan (e.g., in references cited by Inagaki). Numerical values for the “low concentration” are not specified, since such empirical details would be subject to optimization and may differ for each material (or even for various uses of the same material). The skilled artisan, however, would know how to optimize such reaction conditions using routine procedures; determining the optimal concentration would not require “undue” experimentation.

The second step of the process described in paragraph [00045] involves a Diels-Alder type reaction “between the ligands of the organic solvent and the graphite sheets.” The reaction builds “covalent bonds that would maintain the interlayer space of the graphite under operating conditions.” Although no reaction conditions are provided, Diels Alder reactions have been thoroughly studied and are ubiquitously known in the art. There is in particular an extensive literature on Diels-Alder functionalization of fullerenes and carbon nanotubes. For example, Diels-Alder reactions are reported to occur readily with the fullerene allotrope (see page 395 of Diederich, (1997), Pure & Appl. Chem., 69(3):395-400, attached hereto as Exhibit A). The skilled artisan would, again, be capable of referring to such literature and choosing conditions to obtain the desired compositions via a Diels Alder reaction.

Finally, the third step of the process described in paragraph [00045] involves Li intercalation and mechanical milling. As acknowledged by the references cited by the Examiner (e.g., Inagaki as discussed below), intercalation of Li ions and mechanical milling are processes that are well known in the art. Therefore, as with the first two steps, the skilled artisan would need only to optimize the process.

In general, therefore, each of the steps required to prepare compositions according to the claims are well known and understood in the art. Even if the preparation of an optimized composition would require optimization of the reaction conditions in one or more of the above-described steps, the preparation of any composition according to the claims is immediately practicable by the skilled artisan based on the disclosure of the application.

f. The existence of working examples

MPEP §2164.02 clearly states that working examples are not necessary in order to satisfy the enablement requirement under 35 U.S.C. §112, first paragraph:

- An applicant need not have actually reduced the invention to practice prior to filing. In *Gould v. Quigg*, 822 F.2d 1074, 1078, 3 USPQ 2d 1302, 1304 (Fed. Cir. 1987), as of Gould's filing date, no person had built a light amplifier or measured a population inversion in a gas discharge. The Court held that "The mere fact that something has not previously been done clearly is not, in itself, a sufficient basis for rejecting all applications purporting to disclose how to do it." 822 F.2d at 1078, 3 USPQ2d at 1304 (quoting *In re Chilowsky*, 229 F.2d 457, 461, 108 USPQ 321, 325 (CCPA 1956)).

The specification need not contain an example if the invention is otherwise disclosed in such manner that one skilled in the art will be able to practice it without an undue amount of experimentation. In *re Borkowski*, 422 F.2d 904, 908, 164 USPQ 642, 645 (CCPA 1970).

As discussed above and below, the invention is disclosed in the application in such a manner that one skilled in the art would be able to practice it without an undue amount of experimentation. The chemical reactions that may be employed to prepare the claimed compositions or practice the claimed methods are well known in the art, and experimental details may be found in the pertinent art (some of which is described and referenced in the specification).

g. The quantity of experimentation needed

As discussed above, although it may be true that *optimization* of the chemical properties of any particular composition encompassed by the claims may require a significant amount of experimentation, preparation of the claimed compositions in general would not require a great deal of experimentation. Furthermore, optimization of the processes described in the specification would require only routine experimentation, a considerable amount of which may be allowed. See MPEP §2164.06:

The quantity of experimentation needed to be performed by one skilled in the art is only one factor involved in determining whether "undue experimentation" is required to make and use the invention... 'The test is not merely quantitative, since a considerable amount of experimentation is permissible, if it is merely routine...' In *re Wands*, 858 F.2d 731, 737, 8 USPQ2d 1400, 1404 (Fed. Cir. 1988) (citing *In re Angstadt*, 537 F.2d 489, 502-04, 190 USPQ 214, 217-19 (CCPA 1976)).

Contrary to what the Examiner appears to believe (Office Action at 6), the reference in the specification to the use of a large number of configurations in a Monte Carlo simulation is not an indication that a large amount of experimentation is needed. Rather, the number of configurations used in a Monte Carlo simulation is simply a measure of the thoroughness of the simulation, a little like saying “we took this calculation out to n significant digits.” Use of a high number of configurations makes the prediction of the Monte Carlo simulation more likely to be correct, but does not imply that persons of skill in the art would have to do any more work in making use of the prediction. Similarly, the assumptions which the Examiner criticizes as physically unrealistic, such as the use of an infinite periodic crystal, are extremely common and have been used in solid state physics and chemistry for at least a century. Basic inventions and discoveries of our age such as the transistor, the semiconductor laser, and the detailed three-dimensional structure of proteins were guided by models of solids (e.g., the energy band model) derived based on the assumption of an infinite periodic crystal.

In summary, the materials of the claims are prepared using well-known reactions and procedures. Details of such reactions and procedures can be found in the relevant art, and it is therefore unnecessary that they be provided in the current specification. Because the application enables the skilled artisan to prepare the claimed materials and use the claimed methods, applicants respectfully request withdrawal of the rejection.

Rejection under 35 U.S.C. §103(a)

Claims 1, 4-6, 11, 13-18, 21-25, 27, 32, and 36 stand rejected under 35 U.S.C. §103(a) as unpatentable over Rodriguez in view of Inagaki. This rejection is traversed.

The Examiner cites Rodriguez as describing layered carbon compositions, and Inagaki as describing the intercalation of carbon materials with an organic ligand (Action at page 11). Based on the claim construction provided in the Action, the Examiner asserts that the skilled artisan would be motivated to modify the materials of Rodriguez using the “intercalation reaction” described by Inagaki.

Based on the claim construction provided hereinabove, however, Rodriguez in view of Inagaki fails to teach or suggest the materials and methods of the claims. In particular, the “pillared” carbon materials of the application are prepared using a method comprising two

reactions (see claim 17, for example): (1) an intercalation reaction involving an alkali metal and organic ligands; and (2) a further reaction between the organic ligands and the carbon material. Inagaki teaches an intercalation reaction (see page 1084 of Inagaki). Neither Rodriguez nor Inagaki, however, teach carrying out a reaction between a carbon material and organic ligands intercalated therein. Such a process is not even suggested in the cited references. Since a rejection under 35 U.S.C. §103 requires that the reference(s) teach or suggest all of the claimed limitations (see MPEP §2142), the Examiner has failed to meet the requirements for a *prima facie* case of obviousness over the combination of Rodriguez and Inagaki. Applicants therefore respectfully request withdrawal of the rejection.

Rejection under 35 U.S.C. §103(a)

Claim 26 stands rejected under 35 U.S.C. §103(a) as unpatentable over Rodriguez in view of Inagaki and further in view of Janot. This rejection is traversed.

The Examiner states that Rodriguez does not disclose ball milling, but that Janot provides the missing teaching. Regardless of whether Janot teaches ball milling, however, the combination of Rodriguez in view of Inagaki does not teach the preparation of pillared carbon materials (see discussion above). In particular, neither Rodriguez nor Inagaki teach carrying out a reaction between a carbon material and organic ligands intercalated therein. Janot also does not teach carrying out a reaction between a carbon material and organic ligands intercalated therein. Accordingly, Janot does not provide the teachings missing from the combination of Rodriguez and Inagaki. Applicants respectfully request withdrawal of the rejection.

Rejection under 35 U.S.C. §103(a)

Claims 2-3, 8, 19-20, 29, and 34-35 stand rejected under 35 U.S.C. §103(a) as unpatentable over Rodriguez in view of Inagaki and further in view of Chen. This rejection is traversed.

The Examiner states that the limitations set forth in the rejected claims (i.e., doping with alkali metals - claims 2-3 and 19-20; various ratios of metal to carbon atoms - claims 8 and 29; and various uses of the compositions - claims 34-35) are not found in the combination of Rodriguez with Inagaki. Regardless of whether Chen provides the additional limitations, however, the combination of Rodriguez in view of Inagaki does not teach the preparation of

pillared carbon materials (see discussion above). In particular, neither Rodriguez nor Inagaki teach carrying out a reaction between a carbon material and organic ligands intercalated therein. Chen also does not teach carrying out a reaction between a carbon material and organic ligands intercalated therein. Accordingly, Chen does not provide the teachings missing from the combination of Rodriguez and Inagaki. Furthermore, applicants note that the results in Chen were later found to be "due to the impurity water gain/loss present in the hydrogen feedstream rather than to H₂ itself" - see col. 1 of the first page of the PRL article. This provides further evidence that the skilled artisan would not have looked to Chen to provide the teachings missing from Rodriguez and Inagaki. Applicants respectfully request withdrawal of the rejection.

Claim objections

Claims 7, 9-10, 12, 28, 30-31, and 33 are objected to for depending upon a claim that has been rejected (Action at page 9). With the arguments set forth herein, applicants submit that claims 1-6, 8, 11, 13-27, 29, 23, and 34-36 are allowable. The objection to the claims is therefore moot.

CONCLUSION

Applicants submit that the claims of the application are in condition for allowance. Applicants respectfully request withdrawal of the rejections, and prompt issuance of a notice of allowance. If the Examiner has any questions concerning this communication, or would like to discuss the application, the art, or other pertinent matters, a telephone call to the undersigned would be welcomed.

Respectfully submitted,

By:



Isaac M. Rutenberg
Registration No. 57,419
c/o MINTZ LEVIN
1400 Page Mill Road
Palo Alto, California 94304-1124
(650) 251-7700 Telephone
(650) 251-7739 Facsimile
Customer No. 23,980

EXHIBIT A

DIEDERICH, (1997), "Covalent Fullerene Chemistry", *Pure & Appl Chem.*, 69(3): 395-400

Covalent fullerene chemistry

François Diederich

*Laboratorium für Organische Chemie, ETH-Zentrum, Universitätsstrasse 16,
8092 Zürich, Switzerland*

Abstract: A brief introduction to the reactivity principles governing the covalent chemistry of fullerenes is provided. The combination of synthetic fullerene and acetylene chemistry gives access to a family of novel molecular carbon allotropes with interesting physical properties. A versatile strategy for the regioselective preparation of specific bis- through hexakis-adducts of C₆₀ based on the tether-directed remote functionalization was developed. Large changes in chemical reactivity and physical properties occur when the conjugated π -chromophore of the fullerene is reduced in size as a result of increasing functionalization. A novel synthesis of enantiomerically pure derivatives of C₆₀ with chiral addition patterns is described.

INTRODUCTION TO FULLERENE REACTIVITY

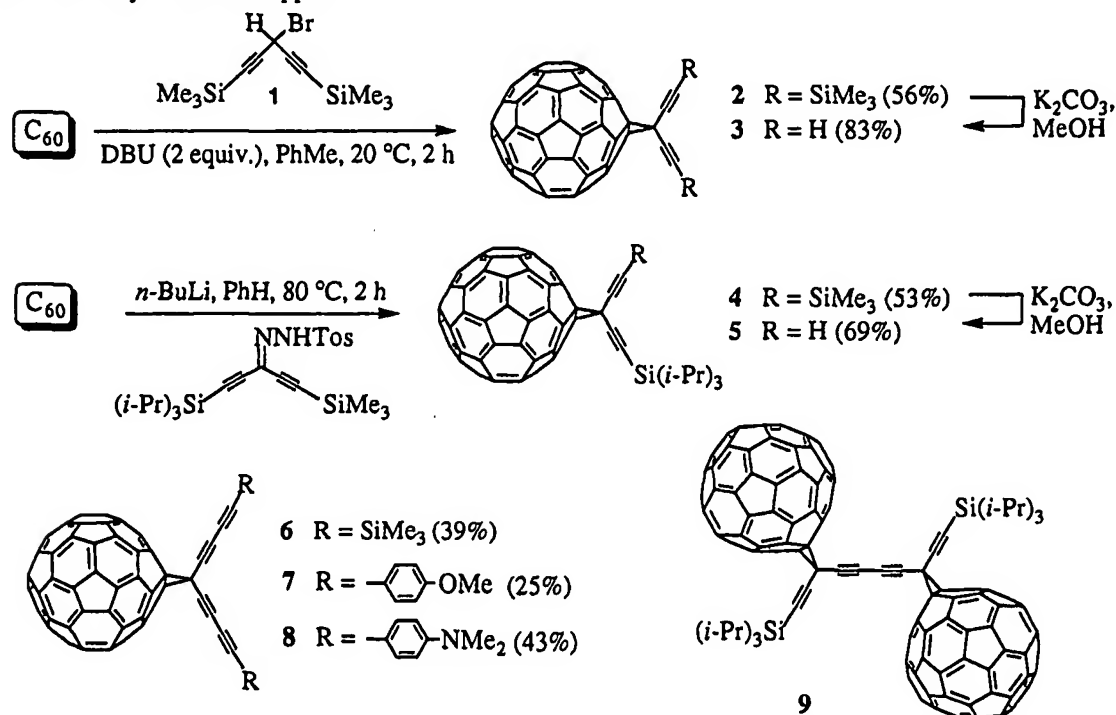
The covalent functionalization of fullerenes (1,2), in particular of the most abundant carbon sphere, buckminsterfullerene C₆₀, has been vigorously developed following the discovery of the bulk preparation method for these carbon allotropes in 1990 (3). A rich variety of methods for the preparation of covalent mono-adducts of C₆₀ are known in which the fullerene reacts as a strained, electron-deficient poly-alkene with rather localized bonds. The molecular carbon allotrope readily adds nucleophiles and carbenes and participates as the electron-deficient dienophile component in many thermal cycloaddition reactions such as the *Diels-Alder* addition. In most of these reactions, 1,2-addition occurs in which the addends add to one of the thirty 6-6 bonds [bonds with high double bond character (bond length ≈ 1.38 Å) at the junction between two six-membered rings]. If both addends in a nucleophilic addition are very bulky, 1,4-addition across a six-membered ring may occur. Thermal 1,3-dipolar cycloadditions of diazoalkanes, α -diazocarbonyls (4), and azides (5,6), followed by elimination of N₂, generate methano- and azafullerenes in which one of the sixty 6-5-bonds [bonds with lower double bond character (bond length ≈ 1.45 Å) at the junction between a six- and a five-membered ring] is bridged. In all mono-adducts formed by 1,2-addition, the fullerene preserves the favorable π -electron system of C₆₀, and all double bonds are located exocyclic to the pentagons, providing [5]radialene character to the pentagons and cyclohexa-1,3,5-triene character to the hexagons. Thus, introduction of a methano bridge at 6-6-bonds produces the 6-6-closed methanofullerene isomer with a transannular bond between the bridgehead C-atoms whereas reaction at 6-5-bonds yields exclusively the 6-5-open isomer in which the two bridgehead C-atoms are at nonbonding distance. The alternative 6-6-open and 6-5-closed isomers are energetically strongly disfavored and do not form because they contain two (6-5-closed) or three (6-6-open) double bonds endocyclic to the pentagons. The 6-6-closed isomer usually is the thermodynamically more stable product, and most 6-5-open methanofullerenes can be converted by thermal, electrochemical, and photochemical methods into the corresponding 6-6-closed derivatives. Most nucleophilic addition processes yield mono-adducts as the main products under appropriate conditions; bis- and higher additions occur more slowly because the electrophilicity of fullerene derivatives becomes increasingly reduced with increasing reduction in the conjugated fullerene π -chromophore. All additions are exothermic and are presumably driven by the relief of strain in the C₆₀ cage that largely results from the pyramidalization of its sp^2 C-atoms. In the adducts, the functionalized fullerene C-atoms change their hybridization from a trigonal sp^2 to a less strained tetrahedral sp^3 state. In this article, the concepts governing fullerene reactivity are illustrated by the formation of methanofullerenes, *Diels-Alder* products, and covalent derivatives resulting from the nucleophilic addition of lithium acetylides to the carbon sphere.

In contrast to the preparation of covalent mono-adducts of C₆₀, the development of selective routes to isomerically pure multiple adducts of the fullerene is still in its infancy (7-10). Monofunctionalized C₆₀

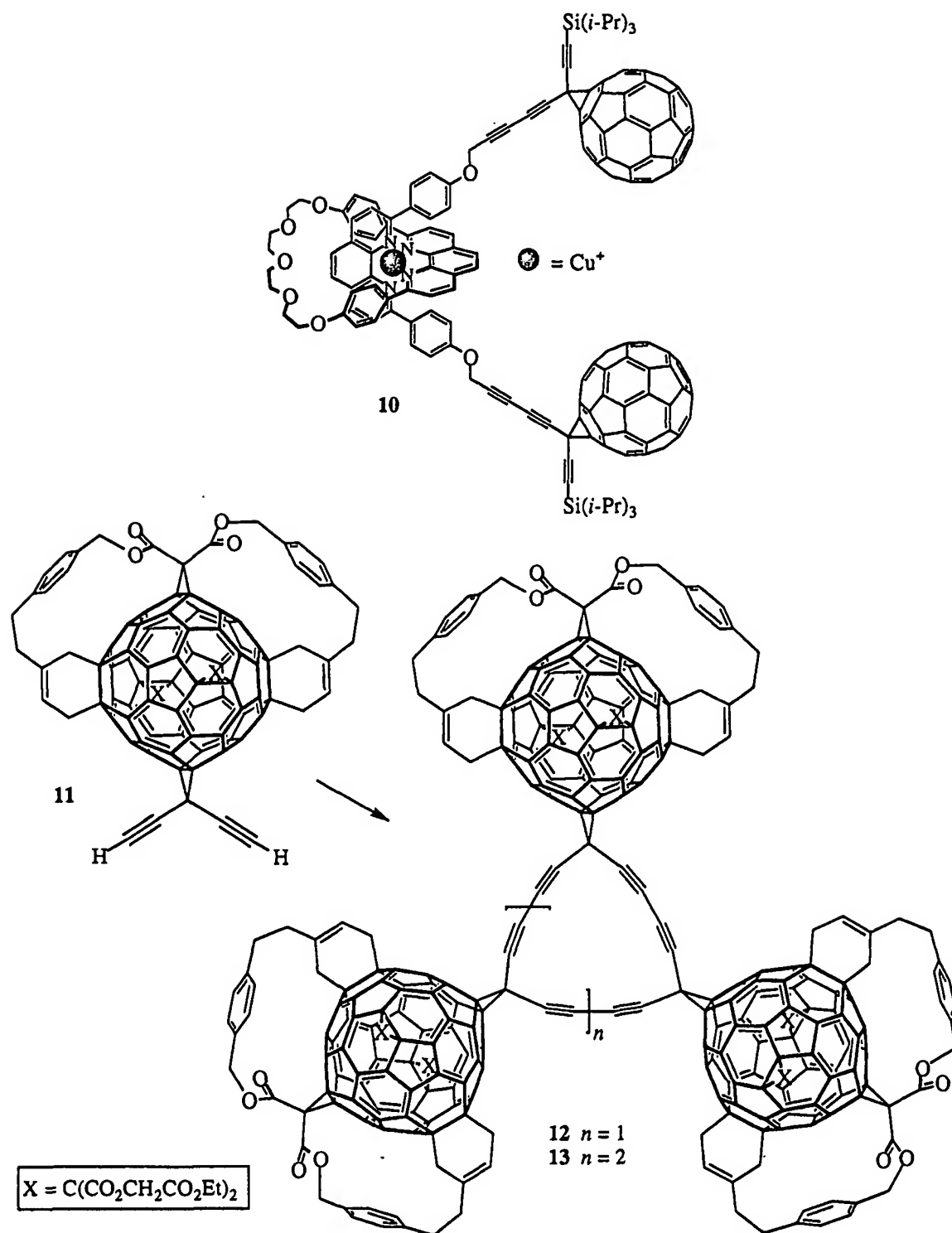
has nine different 6-6-bonds that can react in a second addition, and reactions such as the bis-osmylation (8) or the double *Bingel* cyclopropanation, *i.e.* the addition of bromomalonates in the presence of base (7,11), yielded regioisomeric mixtures of bis-adducts which could only be separated by tedious, scale-limiting high-performance liquid chromatography (HPLC). As illustrated below, we introduced the concept of tether-directed remote functionalization to prepare with high regioselectivity specific bis- through hexakis-adducts of C_{60} (12-15). Since the beginning of bulk scale fullerene chemistry and the isolation and characterization of chiral D_2 -symmetrical C_{76} , prepared from achiral graphite, fullerene chirality has attracted great fascination (16). This article closes with an example for the chiral-tether-mediated enantioselective synthesis of an optically active bis-adduct of C_{60} whose chirality exclusively results from the specific chiral addition pattern (17,18).

FULLERENE-ACETYLENE MOLECULAR SCAFFOLDING

Dialkynylmethanofullerenes are versatile building blocks for molecular construction through oxidative acetylenic coupling. Thus, the parent diethynyl derivative **3** is readily available by treatment of 3-bromo-1,4-pentadiyne **1** with C_{60} in toluene in the presence of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) to give **2**, followed by proto-desilylation (19). Alternatively, the *Bamford-Stevens* reaction was applied to prepare mono-protected **5** via **4** (19,20). Starting from **5**, oxidative hetero-coupling yielded compounds **6-8** which, upon electrolysis, all underwent reductive electrochemical polymerization under formation of an insoluble, air-stable, electrically conducting film depositing on the platinum cathode surface (21). Oxidative homo-coupling of **5** led to the dumbbell-shaped dimeric fullerene **9**, which was characterized by X-ray crystallography. The soluble rotaxane **10** with two C_{60} stoppers was also prepared by hetero-coupling starting from **5** (22). When **10** was reacted with an excess of KCN, the fast atom bombardment mass spectrum showed that the phenanthroline-crown ether macrocoring cannot become unthreaded by slipping over the bulky fullerene stoppers.

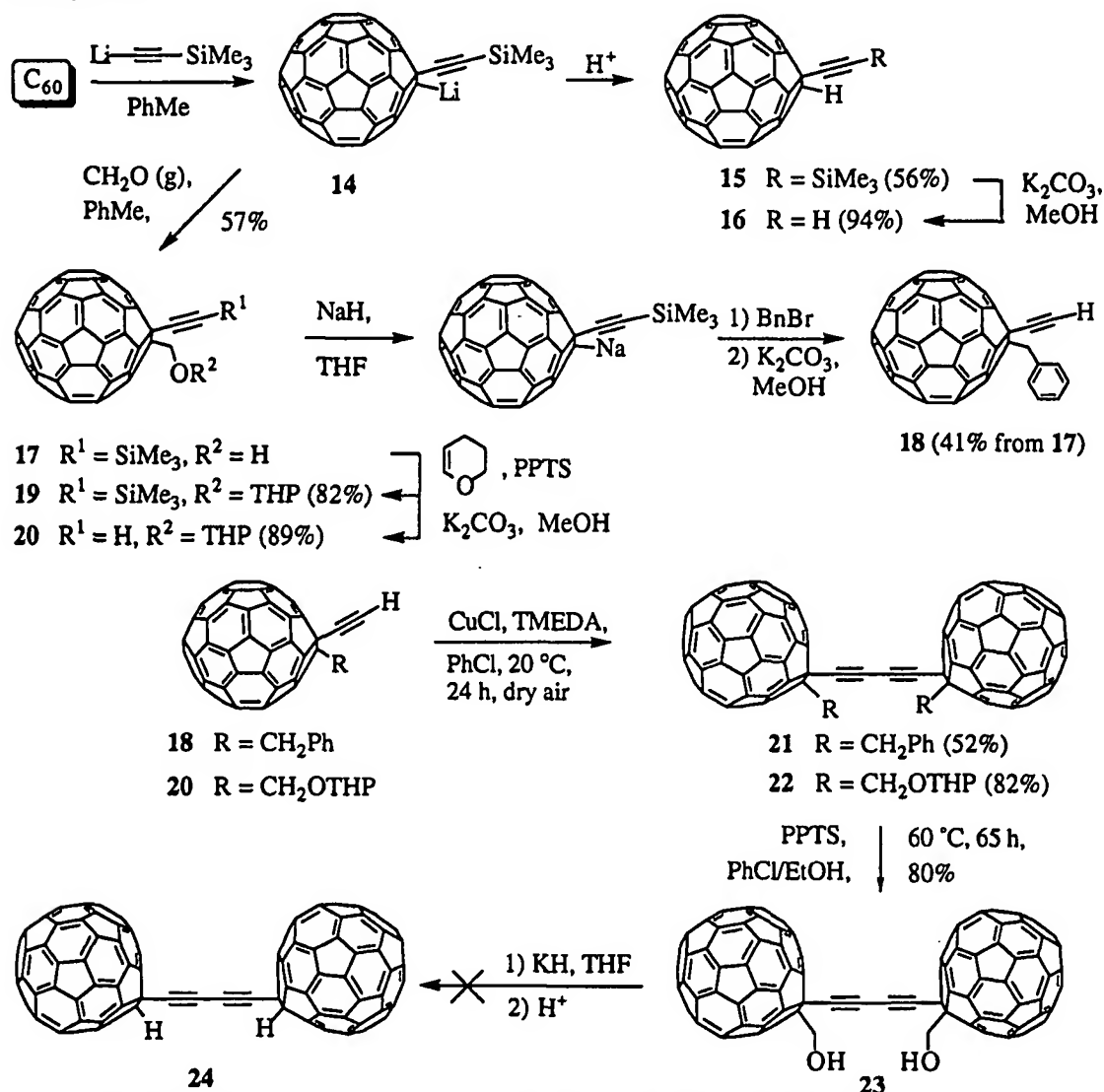


Starting from the diethynylated C_{60} hexakis-adduct **11**, which was prepared by the tether-directed remote functionalization method described below, *Eglinton-Glaser* macrocyclization afforded in a combined yield of 53% trimeric **12** and tetrameric **13** as soluble stable nanomaterials (14). Compounds **12** (MW = 5317 Daltons) and **13** (MW = 7086 Daltons) are solubilized derivatives of C_{195} and C_{260} , members of a new class of molecular carbon allotropes $C_{n(60+5)}$. They can also be viewed as tris- and tetrakis-fullerene adducts of *cyclo*- C_{15} and *cyclo*- C_{20} , respectively; indeed, their MALDI-TOF mass spectra showed as a major fragmentation pattern the sequential loss of the fullerene spheres, which potentially provides a controlled access to the hitherto unknown free cyclocarbons *cyclo*- C_{15} and *cyclo*- C_{20} .



Nucleophilic addition of lithium acetylides provides a method for the direct attachment of alkynyl residues to C₆₀ (19,23). The resulting metallated fullerene 14 can be directly protonated to give 15 and, after protodesilylation, 1-hydro-2-ethynyl[60]fullerene 16. Quenching the anion with formaldehyde leads to methanol 17 which is unstable under strongly basic conditions and rapidly eliminates formaldehyde. The instability of 17 results from the fact that the fullerene anion is a very good leaving group. As a result of a large polarity difference, methanol 17 is readily separated from unreacted C₆₀. In contrast, larger quantities of

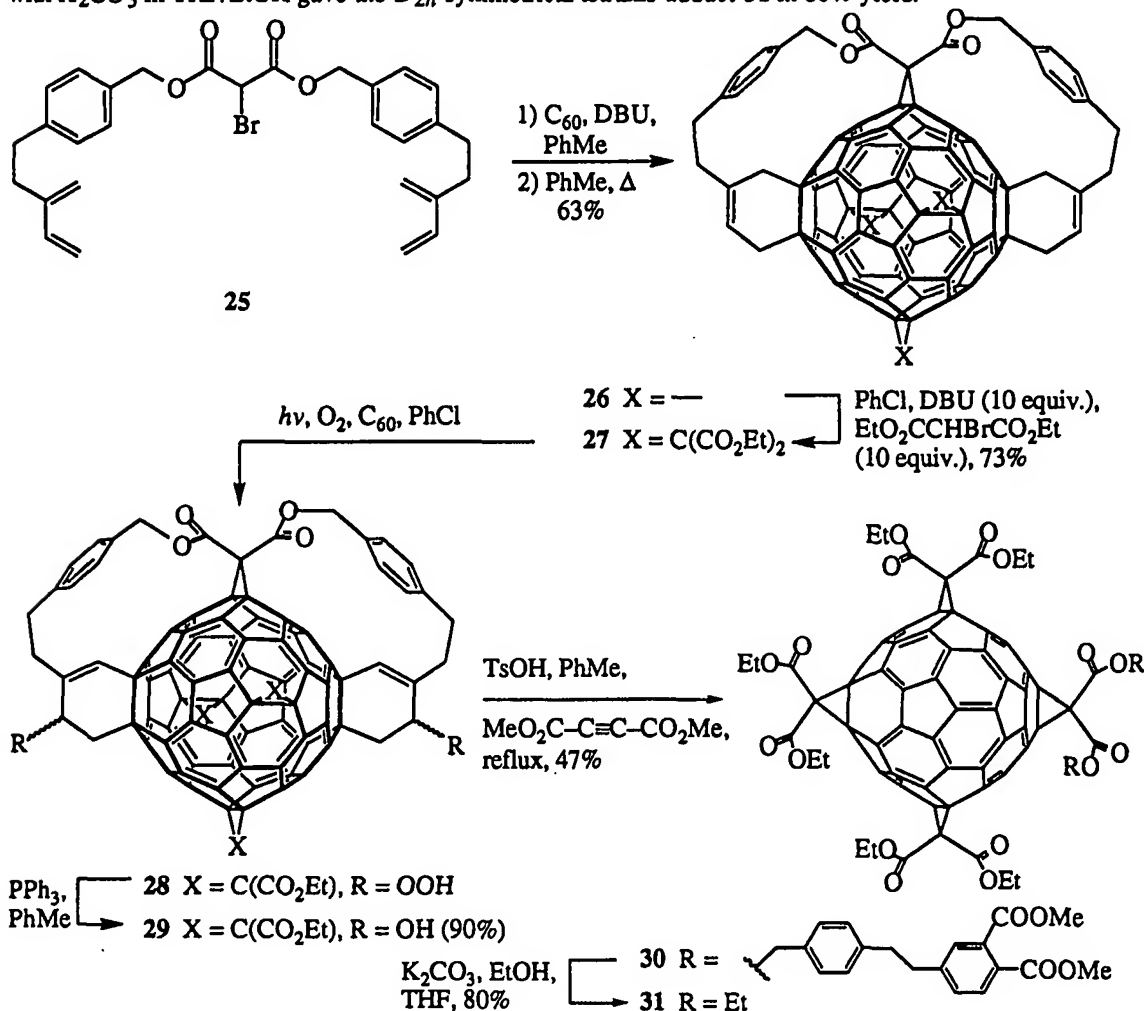
15 or alkylated analogs obtained by quenching 14 with mild alkylating agents are difficult to separate from unreacted fullerene. Therefore, benzylated 18 was best prepared in a one-pot procedure by successive treatment of 17 with NaH in THF, removal of NaH, reflux with benzyl bromide, and finally protodesilylation. Alcohol 17 was transformed into the tetrahydropyranyl ethers 19 and 20, and oxidative Hay coupling starting from 18 or 20 led to the dumbbell-shaped dimeric fullerenes 21 and 22, respectively (24). Cyclic voltammetric measurements revealed that there is no significant electronic communication between the two fullerene spheres in 21 and 22. Deprotection of 22 yielded the highly insoluble dumbbell 23 with two methanol groups. Attempted conversion of 23 to the all-carbon dianion 24 (C_{124}^{2-}) via base-induced elimination of formaldehyde, however, has not yet been successful and is the subject of further investigations.



HIGHER ADDUCTS OF C_{60} BY TETHER DIRECTED REMOTE FUNCTIONALIZATION

The tether-directed remote functionalization method allows construction of fullerene derivatives with addition patterns that are accessible by neither thermodynamic nor kinetic control of reactions with free untethered reagents. Thus the anchor-tether-reactive group conjugate 25 gave, after attachment through a *Bingel* reaction to C_{60} , addition at two *e*-positions (*e*, equatorial with respect to the first addend) on opposite sides of the carbon sphere, yielding tris-adduct 26 in 60% yield with complete regioselectivity (12). Reaction of 26 with a large excess of diethyl α -bromomalonate and DBU in toluene led by sequential *e*-additions in 73% yield to the pseudo-octahedrally functionalized hexakis-adduct 27 in which the

conjugated fullerene π -chromophore is reduced to a cubic cyclophane substructure as shown by X-ray crystallography (14). Other higher C_{60} derivatives with unusual addition patterns not accessible by direct synthetic methods become available by removal of the initially introduced tether-reactive group conjugate (15). When a solution of **27** containing C_{60} as 1O_2 sensitizer was irradiated (medium-pressure Hg lamp, Pyrex filter, 25 °C) while a stream of O_2 was bubbled through, the 1O_2 ene-reaction at the two cyclohexene rings yielded after 2 hours a mixture of isomeric allylic hydroperoxides **28** with endocyclic double bonds (25). Reduction of the crude mixture **28** with PPh_3 (10 equiv.) gave an isomeric mixture of allylic alcohols **29** which was transformed into the bis(cyclohexadieno) derivative by acid-catalyzed dehydration. Further reaction with dimethyl acetylenedicarboxylate (10 equiv.) afforded, via a *Diels-Alder* retro-*Diels-Alder* sequence, the C_{2v} -symmetrical tetrakis-adduct **30** in 42% overall yield starting from **27**. Treatment of **30** with K_2CO_3 in THF/EtOH gave the D_{2h} -symmetrical tetrakis-adduct **31** in 80% yield.

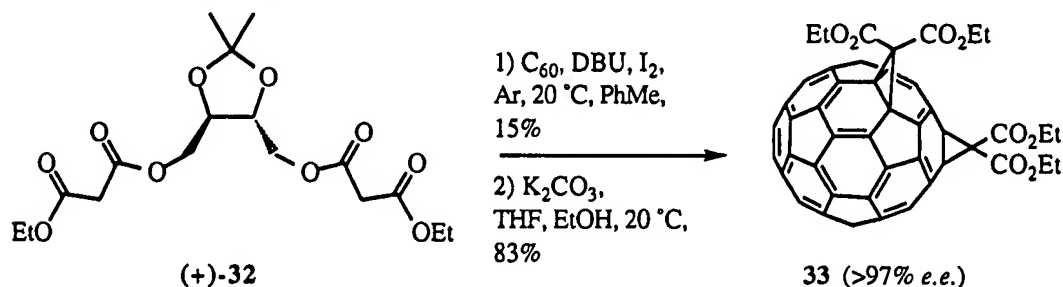


In an extended series of bis- to hexakis-adducts formed by the tether-directed remote functionalization method, the following changes in properties of the fullerene derivatives were observed as a result of the increasing reduction of the π -electron chromophore: a) The higher adducts show reduced reactivity against nucleophilic reagents; thus the Me_3Si alkyne-protecting groups in the precursor to **11** could be readily removed with Bu_4NF , whereas nucleophilic fluoride rapidly attacks the free carbon sphere. b) The colors of the solutions change from purple (C_{60}) to different tones of red and green-yellow (bis- to pentakis-adduct), to yellow (hexakis-adduct **27**). In **27**, the tailing end absorption stops below 460 nm, whereas lower adducts show a cutoff of 560 nm. c) The number of one-electron reduction steps decreases with additional addends from six reversible steps in C_{60} (first reduction at -0.98 V versus ferrocene) to one irreversible reduction in **27** (at -1.87 V) (13). In contrast, oxidation becomes increasingly reversible and facilitated with increasing functionalization, with the hexakis-adduct being reversibly oxidized at $+0.99$ V. The correlation between the degree of functionalization and the changes in redox properties is not entirely

straightforward: the electrochemical properties are not only dependent on the number of addends but also on the regiochemistry of the addition pattern on the surface of the fullerene sphere (13,15).

ENANTIOSELECTIVE SYNTHESIS OF A C₆₀ DERIVATIVE WITH A CHIRAL ADDITION PATTERN

Very recently, we showed that the macrocyclization between C₆₀ and bis-malonate derivatives in a double *Bingel* reaction provides a versatile and simple method for the preparation of covalent bis-adducts of C₆₀ with high regio- and diastereoselectivity (18). Starting from the optically pure bis-malonate derivative **32**, the new bis-functionalization method, followed by transesterification, also permitted the enantioselective preparation of optically active (*cis*-3) bis-adduct **33** whose chirality results exclusively from the addition pattern. With an enantiomeric excess (*e.e.*) higher than 97%, the asymmetric induction in the chirally tethered bis-malonate addition was similarly efficient to that previously reported for the asymmetric *Sharpless* dihydroxylation of C₆₀ (17). The general character of enantioselective multiple functionalizations of fullerenes mediated by optically active, removable tethers is under investigation (26).



REFERENCES

1. F. Diederich and C. Thilgen, *Science* **271**, 317-323 (1996).
2. A. Hirsch, *The Chemistry of the Fullerenes*, Thieme Verlag, Stuttgart, 1994.
3. W. Krätschmer, L. D. Lamb, K. Fostiropoulos and D. R. Huffman, *Nature* **347**, 354-358 (1990).
4. F. Diederich, L. Isaacs and D. Philp, *Chem. Soc. Rev.* **23**, 243-255 (1994).
5. M. Prato, Q. C. Li, F. Wudl and V. Lucchini, *J. Am. Chem. Soc.* **115**, 1148-1150 (1993).
6. A. B. Smith, III and H. Tokuyama, *Tetrahedron* **52**, 5257-5262 (1996).
7. A. Hirsch, I. Lamparth and H. R. Karfunkel, *Angew. Chem. Int. Ed. Engl.* **33**, 437-438 (1994).
8. J. M. Hawkins, A. Meyer, T. A. Lewis, U. Bunz, R. Nunlist, G. E. Ball, T. W. Ebbesen and K. Tanigaki, *J. Am. Chem. Soc.* **114**, 7954-7955 (1992).
9. B. Kräutler and J. Maynollo, *Angew. Chem. Int. Ed. Engl.* **34**, 87-88 (1995).
10. H. W. Kroto, R. Taylor and D. R. M. Walton, *Pure Appl. Chem.* **66**, 2091-2094 (1994).
11. C. Bingel, *Chem. Ber.* **126**, 1957-1959 (1993).
12. L. Isaacs, R. F. Haldimann and F. Diederich, *Angew. Chem. Int. Ed. Engl.* **33**, 2339-2342 (1994).
13. C. Boudon, J.-P. Gisselbrecht, M. Gross, L. Isaacs, H. L. Anderson, R. Faust and F. Diederich, *Helv. Chim. Acta* **78**, 1334-1344 (1995).
14. L. Isaacs, P. Seiler and F. Diederich, *Angew. Chem. Int. Ed. Engl.* **34**, 1466-1469 (1995).
15. F. Cardullo, L. Isaacs, F. Diederich, J.-P. Gisselbrecht, C. Boudon and M. Gross, *J. Chem. Soc. Chem. Commun.* 797-799 (1996).
16. F. Diederich, C. Thilgen and A. Herrmann, *Nachr. Chem. Tech. Lab.* **44**, 9-16 (1996).
17. J. M. Hawkins, A. Meyer and M. Nambu, *J. Am. Chem. Soc.* **115**, 9844-9845 (1993).
18. J.-F. Nierengarten, V. Gramlich, F. Cardullo and F. Diederich, *Angew. Chem. Int. Ed. Engl.*, submitted.
19. P. Timmerman, H. L. Anderson, R. Faust, J.-F. Nierengarten, T. Habicher, P. Seiler and F. Diederich, *Tetrahedron* **52**, 4925-4947 (1996).
20. Y.-Z. An, Y. Rubin, C. Schaller and S. W. McElvany, *J. Org. Chem.* **59**, 2927-2929 (1994).
21. H. L. Anderson, R. Faust, Y. Rubin and F. Diederich, *Angew. Chem. Int. Ed. Engl.* **33**, 1366-1368 (1994).
22. F. Diederich, C. Dietrich-Buchecker, J.-F. Nierengarten and J.-P. Sauvage, *J. Chem. Soc. Chem. Commun.* 781-782 (1995).
23. Y. Murata, K. Motoyama, K. Komatsu and T. S. M. Wan, *Tetrahedron* **52**, 5077-5090 (1996).
24. P. Timmerman, L. E. Witschel, F. Diederich, C. Boudon, J.-P. Gisselbrecht and M. Gross, *Helv. Chim. Acta* **79**, 6-20 (1996).
25. Y.-Z. An, G. A. Ellis, A. L. Viado and Y. Rubin, *J. Org. Chem.* **60**, 6353-6361 (1995).
26. This work was supported by the Swiss National Science Foundation.